Description

PRESSURE ASSISTED WAFER HOLDING APPARATUS AND CONTROL METHOD

BACKGROUND OF INVENTION

[0001] The present invention relates generally to semiconductor device processing equipment, and, more particularly, to a pressure assisted, electrostatic wafer holding apparatus and control method.

[0002] Chucks are used in various material processing systems to retain workpieces (e.g., semiconductor wafers, dielectric substrates, etc.) thereon in a mechanically stationary position while the system process the workpiece. In particular, semiconductor wafer chucks are used to hold substrates in place and/or provide a heat transfer medium to the substrate for various processing steps (e.g., chemical vapor deposition, sputtering, etching, etc.) implemented during the manufacture of semiconductor devices such as integrated circuits.

[0003] There are three general types of chuck mechanism imple-

mentations that may be found in existing industrial wafer processing tools: gravity-based chucks, mechanical chucks and electrostatic chucks. In a gravity based chuck, a wafer is free standing on the chuck and simply held in place by gravity. While this design is the simplest of the three, a significant drawback thereof is the fact that there is an uncontrollable amount of contact between the wafer and the chuck. This is particularly disadvantageous for processes requiring heat transfer between the wafer and the chuck, and especially in low-vacuum processing environments, as this results in a highly non-uniform temperature gradient on the wafer. In turn, this leads to poor thickness control (e.g., for CVD/ALD processes), as well as variations in film properties.

[0004] In a mechanical chuck, a wafer is mechanically clamped to the chuck by means of a retention device, such as an edge ring. While this approach works fairly well for wafers that are somewhat bowed, the use of a mechanical retaining device can generate contaminating particles, as well as create a shadowing effect around the edge of the wafer. In fact, mechanically based chucks are virtually non-existent for semiconductor tooling of 300 mm wafer sizes.

[0005] On the other hand, an electrostatic chuck (ESC) retains a

wafer thereon by generating a charge differential between a surface of the wafer and one or more electrodes located within the body of the chuck. The ensuing electrostatic force developed between the wafer and the electrodes retains the wafer against the chuck body. The electrodes are typically insulated from the wafer by a relatively thin layer of dielectric material. There are several well-known techniques for generating the electrostatic force in an electrostatic chuck. In addition, a typical ESC has an array of raised bumps, the surfaces of which are coated with certain semi-conducting composites such that a high electric field may be established, but not so as to excessively overload the power supply. For example, when a DC voltage ranging from about 200 volts to about 750 volts is applied to the chuck, an electrostatic attraction between the wafer and the chuck is established. This will generally create good contact without the drawbacks associated with a mechanical chuck.

[0006] However, although electrostatic chucks are extensively used in many 200 mm and 300 mm tool sets, there are still some disadvantages associated with electrostatic chucking. For example, electrostatic chucking force is a function of temperature, as well as the backside material

of the wafer. While a higher chucking force may be obtained at a higher chuck and wafer temperature, the raising of the wafer temperature may not be a viable option for certain processes if the raised temperature changes the nature and/or rate of the particular process. Furthermore, for wafers that are more severely bowed (particularly, for a compressively bowed wafer stack), there is insufficient initial contact between the backside of the wafer and the chuck to take advantage of the generated electrostatic forces for adequate retention.

[0007] Accordingly, it would be desirable to be able to implement a chucking apparatus and method that advantageously utilizes the advantages of both electrostatic and mechanical chucking, but that does not suffer from the drawbacks associated therewith.

SUMMARY OF INVENTION

[0008] The foregoing discussed drawbacks and deficiencies of the prior art are overcome or alleviated by an electrostatic wafer holding apparatus. In an exemplary embodiment, the apparatus includes an electrostatic chucking pedestal and a bi-directional backside conduit in fluid communication with a backside of the chucking pedestal. The bi-directional backside conduit is in fluid communication

with a backside carrier gas supply line, and is further in fluid communication with a vacuum supply line.

[0009]   In another embodiment, an electrostatic wafer holding apparatus includes an electrostatic chucking pedestal having an inner zone and an outer zone. A bi-directional backside conduit is in fluid communication with a backside of the chucking pedestal, and is in fluid communication with a backside carrier gas supply line. The bi-directional backside conduit is further in fluid communication with a vacuum supply line. The inner zone and the outer zone of the chucking pedestal are mechanically decoupled from one another.

[0010]   In still another embodiment, a method for implementing pressure assisted electrostatic chucking includes placing a wafer onto an electrostatic chucking pedestal, and introducing a supply of backside carrier gas to a backside of the electrostatic chucking pedestal. The pressure between the wafer and the electrostatic chucking pedestal is monitored to determine whether a threshold level of chucking force exists. The backside carrier gas is decoupled from the backside of said electrostatic chucking pedestal, and the backside of the electrostatic chucking pedestal is coupled to a vacuum supply whenever the actual level of

chucking force is less than the threshold level of chucking force.

BRIEF DESCRIPTION OF DRAWINGS

[0011] Referring to the exemplary drawings wherein like elements are numbered alike in the several Figures:

[0012] Figure 1 is a cross-sectional view of an existing electrostatic chuck;

[0013] Figure 2 is a graph that illustrates the effect of chucking force as a function of temperature;

[0014] Figure 3(a) is a schematic view of a chuck and wafer characterized by a tensile film stack;

[0015] Figure 3(b) is a schematic view of a chuck and wafer characterized by a compressive film stack;

[0016] Figure 4(a) is a cross-sectional view of a pressure assisted, electrostatic wafer holding apparatus, in accordance with an embodiment of the invention;

[0017] Figure 4(b) is a top view of the pressure assisted, electrostatic wafer holding apparatus of Figure 4(a), particularly illustrating the orientation of mini-dipoles on the raised bumps and gas channels of the chuck;

[0018] Figure 5 is a process flow diagram of a method for implementing curvature assisted chucking, in accordance with a further embodiment of the invention;

[0019]   Figure 6 is a top view of a dual-zone electrostatic chuck, in accordance with a further embodiment of the invention;

[0020]   Figure 7 is a cross-sectional view of the dual-zone electrostatic chuck of Figure 6;

[0021]   Figure 8(a) is a cross-sectional view of the dual-zone electrostatic chuck having a wafer characterized by a tensile film stack; and

[0022]   Figure 8(b) is a cross-sectional view of the dual-zone electrostatic chuck having a wafer characterized by a compressive film stack.

DETAILED DESCRIPTION

[0023]   Referring initially to Figure 1, there is shown a cross-sectional view of an existing electrostatic chuck 100. As is known in the art, there are two main components of electrostatic chucking force. When a wafer 102 is first loaded onto the chuck 100, the gap size therebetween is relatively large and, as such, the main attractive force between the two is Coulombic in nature. Once the wafer 102 is attracted to the energized chuck 100 and begins to be flattened as a result, the stronger Johnsen-Rahbek force then becomes the dominant attractive force. However, as indicated previously, conventional electrostatic chucking has certain inherent deficiencies associated therewith. For

example, Figure 2 is a graph that illustrates the effect of chucking force as a function of temperature. Again, while a higher chucking force may be obtained at a higher chuck and wafer temperatures, this may not be a viable option for certain manufacturing processes.

[0024] Moreover, for severely bowed wafers (e.g., the concave wafer 302 of Figures 3(a), the convex wafer 304 of Figure 3(b)), there is not enough contact surface between the backside of the wafer and the chuck. This is particularly the case for wafers having a negative radius of curvature (i.e., convex wafers having a compressively stressed film stack). Thus, the gap distance therebetween is out of the operating range of the stronger Johnsen–Rahbek force. This has become a well-known problem, for example, in its inability to chuck certain SiGe wafers during aluminum stack deposition. Another specific difficulty arises in chucking 300 mm wafers for C4 plating liner seed deposition. For heavily bowed SiGe wafers, it may even be necessary to move the wafer to another deposition tool having mechanical clamps. During the deposition of a metal stack, such as Ti/TiN/Al/Ti/TiN, for example, metals such as Ti ad Al become oxidized in the presence of air. Thus, this is not a practical option and thus the wafer is

scrapped as a result.

[0025] Therefore, in accordance with an embodiment of the invention, there is disclosed a pressure assisted, electrostatic wafer holding apparatus 400 that utilizes a bi-directional backside conduit. As shown more particularly in Figures 4(a) and 4(b), the apparatus 400 includes a chucking pedestal 402 with mini-dipoles 414 and gas channels 415. A backside supply line 406 is used to provide a carrier gas to the backside of the wafer through conduit 408 in fluid communication therewith, while a vacuum supply line 410 is also in selective fluid communication with conduit 406, and controlled by detection circuitry 412. Figure 4(b) is a top view of the pressure assisted, electrostatic wafer holding apparatus 400 of Figure 4(a), particularly illustrating the orientation of mini-dipoles 414 on the raised bumps of the chucking pedestal 402.

[0026] Under normal operation of apparatus 400, when a wafer applied thereto is relatively flat, the conduit 408 is used to flow a small amount of backside gas for wafer detection and operation, as well as to improve the thermal transport between the temperature controlled chuck and the wafer. On the other hand, if the film stack on the wafer is very

compressive, for example, the detection circuitry 412 detects the large (negative) curvature and switches the gas conduit 408 to a vacuum mode of operation. Simultaneously, a front side gas flowing into the chamber (not shown) increases the pressure differential such that the wafer will be assisted in deflecting toward the chuck, thereby enabling the Johnsen-Rahbek force to take effect.

[0027] Referring now to Figure 5, there is shown a process flow diagram of a control method 500 for implementing pressure assisted electrostatic chucking, in accordance with a further embodiment of the invention. Beginning at block 502, a wafer is positioned on an electrostatic chuck, such as apparatus 400 described above, for example. Initially, a backside gas is supplied to the chuck pedestal and the resulting pressure between the wafer and chuck is monitored, as shown in block 504. If at decision block 506 it is determined that the pressure is within specified limits, then sufficient chucking force exists and thus normal wafer processing may proceed as shown at block 508.

[0028] However, if sufficient chucking force is not detected, then method 500 proceeds to block 510 where front side gas flow is introduced, and the gas conduit is coupled to the vacuum supply in an attempt to achieve sufficient chuck-

ing force. Then, decision block 512 again determines whether the pressure is now within specified limits. If this is the case, then the vacuum supply is removed, the backside gas supply is restored and normal wafer processing may proceed. However, if there is still insufficient chucking force, then method 500 proceeds to decision block 514 to see whether the electrostatic chuck voltage is less than the maximum allowed value. If the electrostatic chuck (ESC) voltage does not exceed the maximum value, then the ESC voltage is increased at block 516 before method 500 returns to block 512. This sequence may continue until the chucking force becomes sufficient or until the ESC voltage exceeds the maximum value. As further shown at decision block 514, when the ESC voltage exceeds the maximum value (and the pressure is still not within the specified limits), the process exits at 518, and the wafer is deemed to be too bowed (or broken), and will be scrapped as defective.

[0029] Referring generally now to Figures 6 and 7, there is shown a dual-zone electrostatic chuck 600, in accordance with an alternative embodiment of the invention, in which an inner zone 602 and an outer zone 604 are mechanically decoupled from one another. In particular, the height of

the inner zone 602 is independently adjustable with respect to the height of the outer zone 604, and vice versa. As illustrated in Figure 7, adjustment of the height of the zones may be accomplished through a suitable micro-positioning control mechanism, such as through stepping motor 606 and extendable shaft 608 assemblies mounted on a base 610. As is the case with the embodiment of Figures 4(a) and 4(b), the dual-zone ESC 600 is provided with both a carrier gas supply 612 and a vacuum supply 614.

[0030] The advantages of the dual-zone embodiment are appreciated upon consideration of the condition in which a wafer is curved either in a concave or a convex orientation. In the case where the wafer 616 has a relatively large radius of curvature, the micro-positioning control can raise the outer zone 604 slightly with respect to the inner zone 602 so as to bring the inner zone 602 in closer proximity to the center portion of the wafer 616, as shown in Figure 8(a). Conversely, if the wafer 616 has a relatively large negative radius of curvature, then the outer zone 604 may be retracted slightly with respect to the inner zone 602 so as to bring the outer zone 604 in closer proximity to the outer portions of the wafer 616, as shown in Figure 8(b). Once the bowed wafer is flattened

due to the assisted electrostatic forces, the chucking voltages in both zones may be reduced before continuing with normal processing. In either instance, it will be seen that the closer physical proximity of the wafer and chuck pedestal using the dual-zone embodiment will further facilitate a stronger chucking force and improve device yield.

[0031] While the invention has been described with reference to a preferred embodiment or embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.